devices, power supply, heat dissipation, and size. Raising power would reduce or eliminate the possibility of battery powered units which could be used to provide a personal locator service. And, raising power would increase the interference generated into the other system, thereby giving the operator of that system an incentive to raise power.

The third solution raises total energy in the pulse by increasing the duration of the transmitted pulse. A pulse that lasts twice as long has twice as much energy. Unfortunately, during the longer pulse, twice as much interfering energy gets into the receiver. But receiver processing can normally recover some advantage from longer pulses. Typically, a pulse that is four times as long is effectively twice as powerful.[9] Thus, transmitting pulses that are 100 times as long would have the same effect in combating interference as does raising power by a factor of 10 (say, from 5 watts up to 50 watts). But transmitting longer pulses reduces the time available for other vehicles to transmit. If pulses are twice as long, only half as many vehicles can be supported with vehicle location service. In order to get a 10 dB improvement in signal-to-noise ratio, the capacity drops at least one hundred fold. A system that could provide frequent vehicle location information to 50,000 vehicles becomes able to serve only 500 vehicles.

Any of these remedies has significantly adverse consequences. Multiplying the number of receive sites vastly increases system capital and operational costs. Increasing total pulse energy by increasing transmitted power is economically and technologically impossible. Increasing pulse energy by increasing pulse duration causes an enormous loss of capacity.

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[9]   This assumes, the best case, that the noise or interference is uncorrelated with the desired signal and that the receiver can maintain coherent integration over the longer pulse. In the worst case, there is no improvement in signal-to-noise ratio.

A fourth alternative is to use antenna directionality at the receive site to discriminate against unwanted interference. However, this appears unworkable. First, the interfering transmitter may be located close to the vehicle. If so, the interfering radio waves come from the same direction as the desired waves and a directional antenna cannot discriminate against the unwanted signal. Second, the desired signal comes from an unknown direction and therefore the receive antenna gain should be approximately omni-directional. If we assume that the interfering signal comes from pulses emitted by moving vehicles traveling throughout the served area, then both desired and undesired pulses can come in from any direction, making the use of directional techniques impractical.

3.6 Limitations of the Accuracy Impairment Model

The model presented above probably underpredicts the problem caused by the interference considered. While it properly models the effects of radio signal attenuation it does not take into account all the effects of multipath. Multipath degrades the performance of a TOA VLS system. For example, when a car is in an underpass, the radio pulse cannot travel directly to the receive sites. Instead, the pulse must reflect off nearby buildings or find some other indirect path to the receivers. This indirect path reduces the accuracy of the location estimate. Furthermore, just as ghosts impair television reception, ghosts (multipath signals) may impair the reception of the desired signal. The 902 to 928 MHz band contains multiple sources of noise and interference. The model presented here did not consider the combined effects of multipath and existing noise and interference. In Teletrac's systems these problems are overcome by additional receive sites and clever algorithms that combine TOA data from many sites.

The model assumes that the generalized interfering signal is broadly representative of unknown co-channel interference. However, it is not a "worst case" simulation.

The model does not take into account the possible worst case of antenna placement. Many of the mobile units served by Teletrac have hidden antennas which prevent thieves from easily disabling the vehicle location system. Such hidden antennas typically have antenna gains in the range -6 to -12 dB. We have used the high-end (most optimistic) of this range in our calculations. The reader can adjust the results shown in the chart to reflect the lower gain mobile antenna, by increasing the interfering power by a factor of four.

Similarly, the model does not illustrate or quantify the problems of determining in the presence of interference the location of a vehicle far from the nearest receivers. Teletrac's system currently is able to provide accurate location information for mobile units as far as 15 miles or 20 miles from the nearest receive sites. GDOP effects are minimized when the vehicle is inside the array of receive sites. GDOP is increased as the mobile unit moves away from the array of receive sites. Unfavorable GDOP increases the error by a factor of two to three.

3.7   Conclusions on Accuracy

The accuracy of a wideband TOA VLS system will be seriously degraded by the operation of a co-channel system in the same geographic area. The model presented here shows that an interfering transmitter will increase the location error to well beyond levels acceptable to consumers. The model supporting these conclusions is conservative in the sense that it omits ambient noise, multipath and antenna effects that would further reduce system performance.

Possible remedies to such harmful interference have two negative effects on system performance. Either they degrade capacity enormously or they increase costs substantially or both. Reduced capacity and increased costs reflect losses of spectrum efficiency and losses to the public interest.

Given the model results and the conservative nature of that model and the lack of any feasible remedy to such interference the need for a distance separation requirement for co-channel systems is readily apparent.

4   INTERFERENCE EFFECTS ON COVERAGE

The above discussion of interference considered an idealized situation which, while complex, was still simple enough to describe relatively briefly. There were only four receive sites and there were no geographical features, such as hills, which could block radio signal propagation.

This section expands that model by considering the effects of a co-channel interfering system on geographic coverage in a real world environment. In this section, we consider predicted interference effects in the Chicago metropolitan region using the site locations of Teletrac's existing system in Chicago and taking into account the actual geography.

4.1   Overview

As discussed in Section 1, consumers require AVM services to be available at any time and wherever they may be. Analyzing the first issue, the effects of interference on the time availability of an AVM system is difficult since a key issue is the time pattern of operation of the interfering signal. Consequently, we have not attempted any computer modeling of time patterns of interference. However, we will offer our observations on this point at the end of this section.

Analyzing the effects of an interfering signal on the geographic coverage of the AVM system is somewhat more straightforward. Here, once we define the nature and location of the interfering signal, we can perform the radio engineering calculations to determine the effects of interference on geographic coverage.

The discussion that follows first describes how we performed such coverage analysis. Then it shows the substantial impairments to coverage caused by co-channel interference. And, finally, we offer our conclusions.

4.2 Methods of Analysis

As before, when we were studying the effects of interference on accuracy, we used a computer model to predict system performance. In this case, the performance attribute we are looking at is geographic coverage. In particular, under each interference scenario, we will show the regions within the Chicago urban area where the Teletrac AVM system is predicted to generate acceptable location estimates. Upon comparing the results of various scenarios the reader can see and understand the loss of coverage created by co-channel interference.

Our analysis proceeds in several steps. We have chosen the Chicago urban area since Teletrac already has a system operating there. The existing system defines the receive sites used in the simulation. These receive sites were chosen to give high quality coverage, subject to the constraints of the real estate market. A system operator cannot always locate a receive site in a park or on a church, even if those locations make the most sense from a radio engineering point of view. Additionally, Teletrac is constrained by zoning laws and aesthetic conditions and therefore Teletrac's policy is to locate on existing radio towers.

We use the USGS 30-second terrain file as the terrain data source in the propagation model. The propagation model used is a Teletrac model which has performance similar to the Lee model.[10] It includes all the usual path loss factors: free-space, rough-earth diffraction, knife-edge diffraction, obstructions, etc.

The software used in this analysis is the same package Teletrac uses to engineer coverage in urban areas, to determine optimum site locations, and to identify areas of poor coverage. We have found the match between model predictions and measured coverage to range from very good to excellent based upon literally millions of automated field measurements made since 1987.

Given these receive sites and the propagation model, the analysis proceeds in the following fashion.

- The Chicago metropolitan area is covered by a closely spaced grid of points.

- We pick one of these points and calculate the received signal level at all receive sites from a vehicle located at this point. The calculation of the received signal level takes into account terrain variations, and the height of the receive site antenna.

- At each receive site, the ratio of signal to noise and interference (SNIR) is calculated.

- The receive sites are classified into two categories, useful and not useful, by SNIR. The dividing line between the two categories is based upon a 90 percent probability that the receive signal level is high enough to provide reliable TOA values. That is, paralleling the operation of the actual system, we reject the data with low signal to interference and noise ratios.

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[10]   The radio channel model is discussed in greater detail in subsection 4 below. For a description of the Lee Model, see *IEEE Trans on Vehicular Technology*, Vol. 37, No. 1, "Coverage Prediction for Mobile Radio Systems Operating in the 800/900 MHz Frequency Range," February 1988, pp. 3-70.

- Taking into account the number of acceptable receive sites, SNIR and GDOP we calculate whether the standard deviation of the radial location error is less than 150 feet.

- If the standard deviation of this error is less than 150 feet, the point is marked on a map as covered.

- We repeat the above five steps for every point on the grid and thereby draw a coverage map.

4.3 Effects of Interference on Coverage

We consider three different interference scenarios:

(1) No interference.

(2) A 10 watt CW interfering source, located inside the service area and six feet above the ground. This source represents an interfering mobile unit.

(3) A 300 watt CW interfering source, located at the edge of the service area and with an antenna height of 250 feet. This interference source represents a co-channel base station.

Figure 8 shows the region of interest, the greater Chicago area. Lake Michigan is on the right. O'Hare Airport is near the center. Figure 8 is a reproduction of a map used to describe Teletrac's service to potential customers.
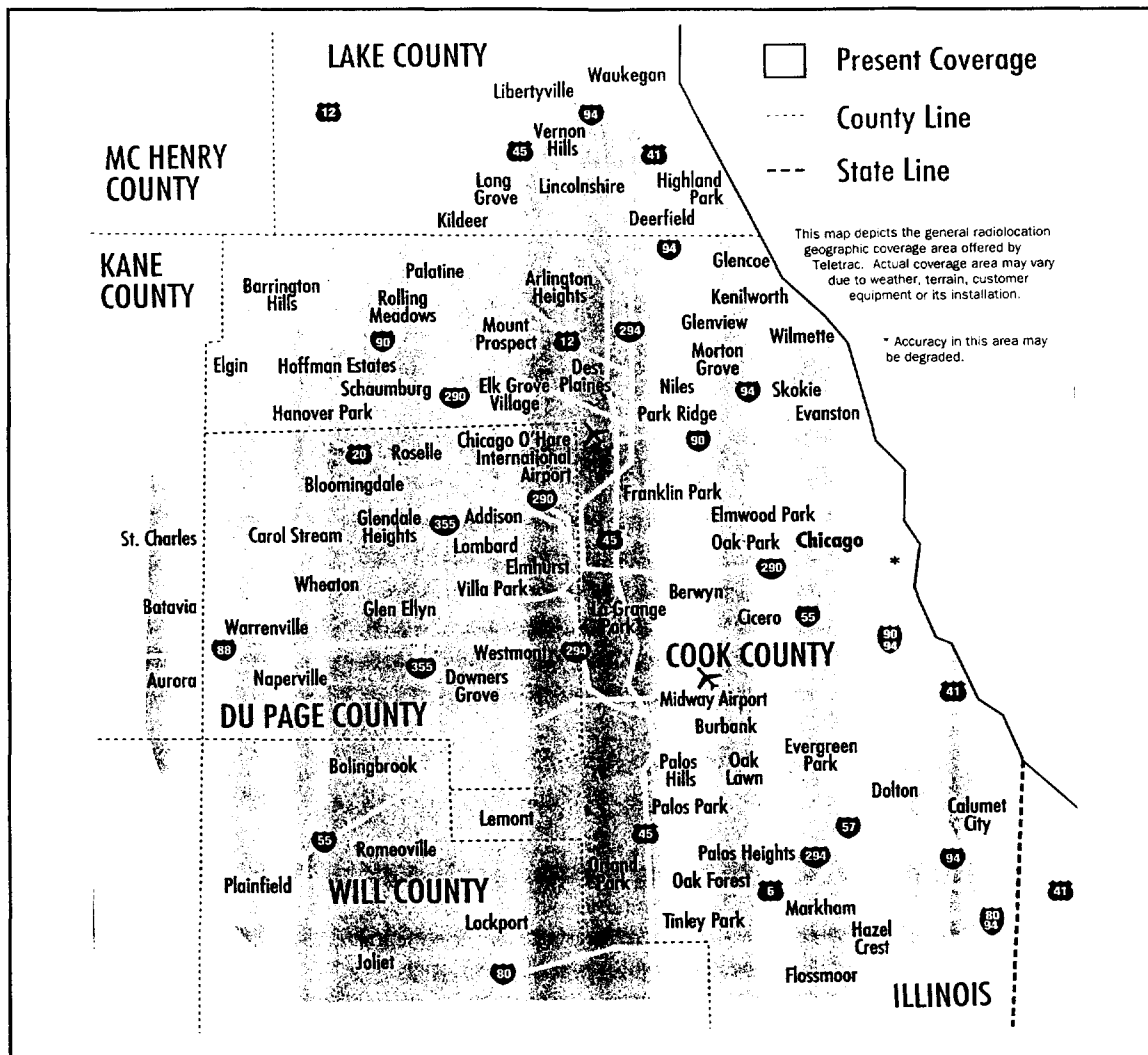
LAKE COUNTY

Present Coverage

County Line

State Line

Waukegan

Libertyville

Vernon Hills

MC HENRY COUNTY

Long Grove Lincolnshire

Highland Park

Kildeer

Deerfield

This map depicts the general radiolocation geographic coverage area offered by Teletrac. Actual coverage area may vary due to weather, terrain, customer equipment or its installation.

KANE COUNTY

Palatine

Glencoe

* Accuracy in this area may be degraded.

Barrington Hills

Rolling Meadows

Arlington Heights

Kenilworth

Mount Prospect

Glenview

Morton Grove

Wilmette

Elgin   Hoffman Estates

Des Plaines

Niles

Skokie

Schaumburg

Elk Grove Village

Park Ridge

Evanston

Hanover Park

Roselle

Chicago O'Hare International Airport

Bloomingdale

Franklin Park

St. Charles

Glendale Heights

Addison

Elmwood Park

Carol Stream

Lombard

Oak Park   Chicago

Elmhurst

Wheaton

Villa Park

Berwyn

Glen Ellyn

La Grange Park

Cicero

Warrenville

Batavia

Westmont

COOK COUNTY

Aurora

Naperville

Downers Grove

DU PAGE COUNTY

Midway Airport

Burbank

Evergreen Park

Bolingbrook

Palos Hills Oak Lawn

Dolton

Calumet City

Palos Park

Lemont

Palos Heights

Romeoville

Oak Forest

Markham

Plainfield

WILL COUNTY

Tinley Park

Hazel Crest

Lockport

Joliet

Flossmoor

ILLINOIS

Figure 8   Chicago Service Area

Figure 9 shows the base case coverage with the current noise and interference environment. Coverage is generally excellent inside a contiguous area of 2,332 square miles. The "+" marks indicate points of acceptable coverage. No mark is made at points without coverage. The indicated coverage is solid from Chicago proper out to Interstate 294. Outside 294 there are holes in the coverage as the edge of the reliable service area is reached. For example, the gap in coverage to the southwest of the intersection of 294 and 55 is the valley of the Des Plaines River. Note also that the system is able to obtain acceptable signals at an average of 7.1
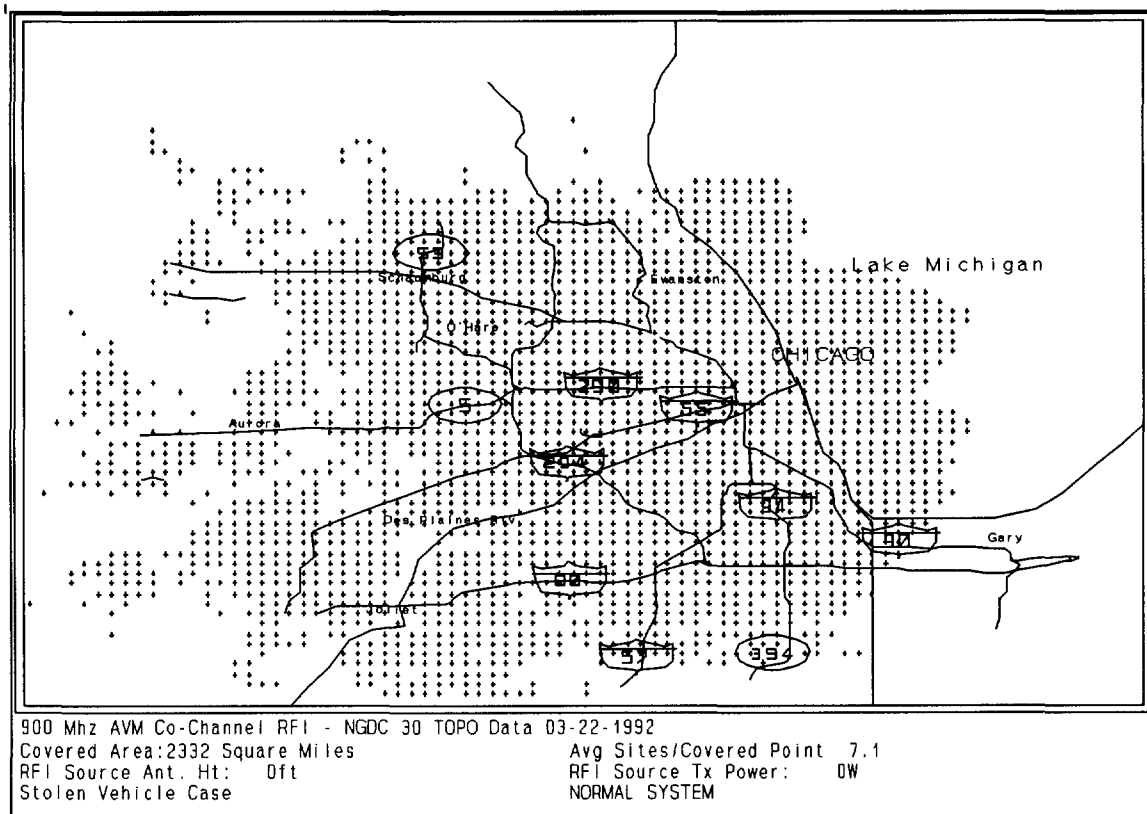
```
900 Mhz AVM Co-Channel RFI - NGDC 30 TOPO Data 03-22-1992
Covered Area:2332 Square Miles              Avg Sites/Covered Point  7.1
RFI Source Ant. Ht:   0ft                   RFI Source Tx Power:     0W
Stolen Vehicle Case                         NORMAL SYSTEM
```

Figure 9 Normal Coverage In Chicago Area

receive sites per covered point. Such multiple coverage allows for high quality location estimation and provides a measure of redundancy in the fixed network.

Figure 10 shows the reduced coverage with a 10-watt interfering source located at the intersection of Interstates 55 and 294. This point is about 15 miles south of O'Hare airport. Coverage drops dramatically to only 672 square miles and service is no longer provided in downtown Chicago. Service at those points still covered has dropped in quality. There are now only an average of 4.3 receive sites per covered point, down from the 7.1 sites on average of the earlier scenario. Recall that a minimum of four sites per point are required to calculate an unambiguous location. Thus, we have dropped from having, on average 3.1 additional or supplementary measurements of time of arrival, to only 0.3 supplemental measurements. This

data loss will degrade the accuracy of location estimates and it has also removed the reliability

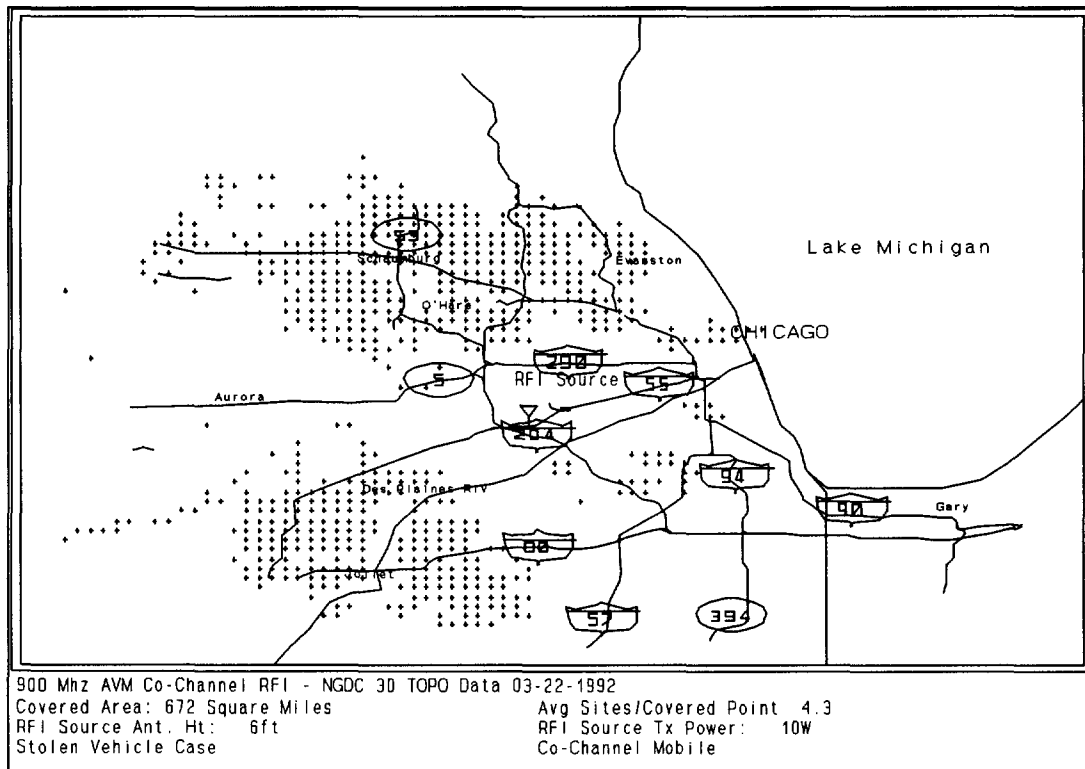provided through the effective parallel redundancy of equipment.

900 Mhz AVM Co-Channel RFI - NGDC 30 TOPO Data 03-22-1992
Covered Area: 672 Square Miles   Avg Sites/Covered Point 4.3
RFI Source Ant. Ht: 6ft   RFI Source Tx Power: 10W
Stolen Vehicle Case   Co-Channel Mobile

Figure 10 Reduced Coverage with Interfering Mobile in Service Area

Figure 11 shows the coverage if we increase the assumed interfering power from 10 watts to

300 watts, assume an antenna height of 250 feet and a transmitter 40 miles from Chicago. We

feel that this configuration represents well the type of interference that would be generated by

a fixed transmitter in a co-channel AVM system. In this case the interfering transmitter is

located well to the west, just north of the East-West Tollway in Aurora and is about 40 miles

from the heart of Chicago.[11]

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[11]   When we ran the simulation with a 300 watt transmitter located inside the coverage
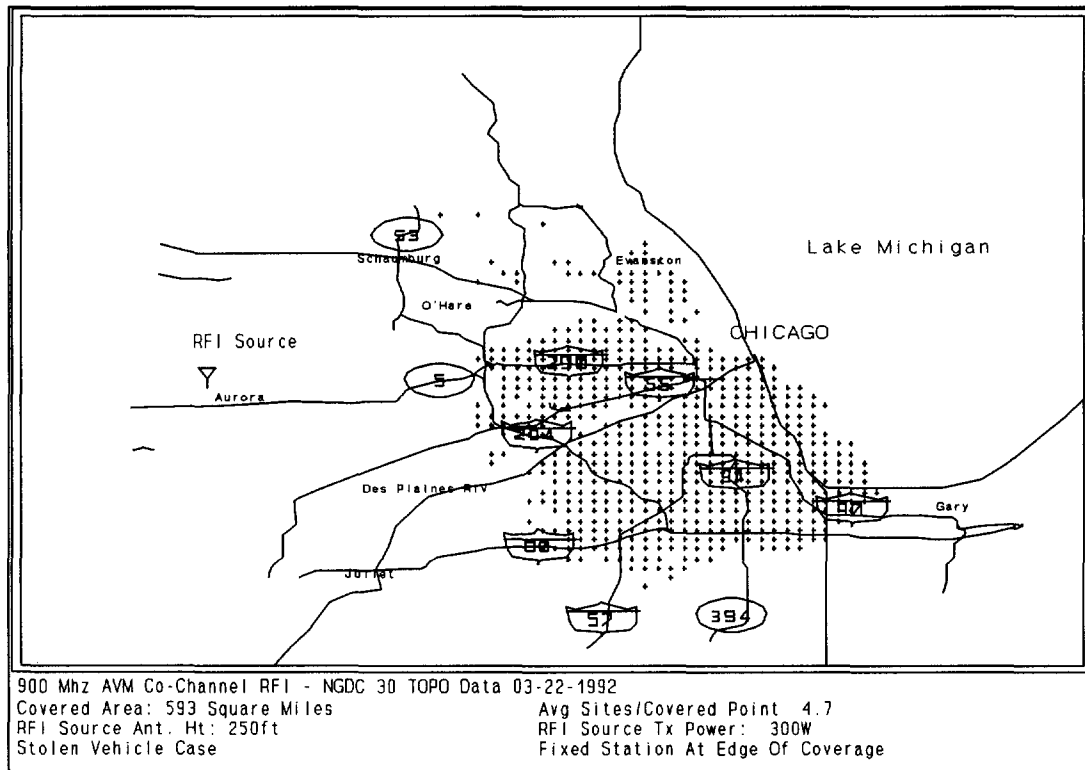area, all receive sites experienced excessive interference.

Figure 11 Reduced Coverage with Fixed Interference

Even with this distance separation, coverage plummets. Coverage falls to 593 square miles and there are only 4.7 receive sites on average per covered point. Notice that there is <u>no</u> coverage within about 20 miles of the interfering transmitters.

These interference effects are shown in tabular form below.

Coverage Reduction Caused by Co-channel Interference				
Interference Scenario	Coverage (square miles)	Coverage (percent of base case)	Average Site Count Per Point[12]	Site Count Margin
Base case (existing noise and interference)	2,332	100	7.1	3.1
Ten watt mobile in service area	672	29	4.3	0.3
Three hundred watt fixed station at edge of service area	593	25	4.7	0.7

4.4   Conclusions on Coverage

We have presented the results of two interference scenarios.   Even a moderately powered interfering source located inside the service area reduces coverage substantially.   A high power interfering source, transmitting at the edge of the service area similarly damages coverage.   Not displayed in these figures are the effects on reliability and accuracy on those points still marked as covered.   Accuracy will be degraded at those points compared to the interference-free case. The reader should keep those additional losses in mind.

We have not tried to model time patterns of coverage loss.   It is reasonable to suppose that the interfering transmissions from a co-channel AVM system would be continuous.   The current interim rules permit operation of a wide variety of AVM system designs.   Systems using multiple wideband, high-power CW signals to provide ranging information are realistic possibilities.   The reader can supply his or her own model of the time distribution of interference activity, and estimate its effects given the detrimental effects on coverage we have shown for a single interfering source.

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[12]   Recall that a minimum of four receive sites are needed for operation.

5   CONCLUSIONS

We have looked at co-channel interference in two different ways. First, we looked at a simplified scenario and showed how co-channel interference affected the accuracy of a TOA VLS system. The results were striking. Co-channel interference vastly reduces the accuracy of location estimates. Or putting it another way, interference increases the location uncertainty associated with a location estimate. A tow truck can reasonably be dispatched to a location such as "Route 2, just south of the intersection with Main Street." It cannot be dispatched with instructions such as "There is a motorist in distress somewhere in the eight-square-block area centered on the intersection of Route 2 and Main." But the degradation in accuracy caused by co-channel interference moves us from the first case to the second.

Second, we looked at the impacts of co-channel interference on predicted coverage in the Chicago urban area. Here we saw that even moderately powered mobile units operating inside the service area substantially degraded coverage as did fixed stations located on the edge of the service area.

These two analyses point to one conclusion: a wideband AVM system, such as Teletrac's, cannot operate in the presence of co-channel interference of the type that would be generated by additional wideband AVM systems or additional high powered CW carriers in the region.

ATTACHMENT A: Letter from Gerald N. Quindt, 12/3/91

ATTACHMENT B: Letter from H. Chet Galland, 11/24/91

ATTACHMENT C: Letter from Lt. George L. Scharm, 12/5/91

ATTACHMENT D: Letter from Inspector Joseph A. Koenig,
                 11/22/91

ATTACHMENT E: Letter from Phillip Bailey, 4/2/92; letter
                 William W. Johnson, 11/23/91

ATTACHMENT F: Letter from Gary L. Anderson, 7/8/91

ATTACHMENT G: Letters from Commander James L. Harris,
                 7/8/91; District Attorney Ira Reiner,
                 10/8/91; Steven Cohen, 11/18/91; Chief
                 William Dwyer, 11/20/91; Commander Roy L.
                 Newman, 12/16/91; Special Agent Delbert N.
                 Dilbeck, 12/18/91

ATTACHMENT H: Trimble News Release, 3/2/92

ATTACHMENTS

ATTACHMENT A: Letter from Gerald N. Quindt, 12/3/91

ATTACHMENT B: Letter from H. Coapt Galland, 11/24/91

ATTACHMENT C: Letter from Charles Devlin, 11/22/91

ATTACHMENT D: Letter from D. Gualino, 11/25/91

ATTACHMENT E: Letter from Rick Hernandez, 4/2/92

ATTACHMENT F: Letter from Lt. George L. Scharm, 12/5/91

ATTACHMENT G: Letter from Inspector Joseph A. Koenig, 11/22/91

ATTACHMENT H: Letter from Phillip Bailey, 4/2/92; letter William W. Johnson, 11/23/91

ATTACHMENT I: Letter from Gary L. Anderson, 7/8/91

ATTACHMENT J: Letters from Commander James L. Harris, 7/8/91; District Attorney Ira Reiner, 10/8/91; Steven Cohen, 11/18/91; Chief William Dwyer, 11/20/91; Commander Roy L. Newman, 12/16/91; Special Agent Delbert N. Dilbeck, 12/18/91

ATTACHMENT K: Trimble News Release, 3/2/92

≡EXECUTONE®

December 3, 1991

Mr. John Polcari, Account Executive
INTERNATIONAL TELETRAC SYSTEMS, INC.
9800 La Cienega Boulevard, Suite 800
Inglewood, CA 90301

Dear Mr. Polcari,

Teletrac has greatly helped EXECUTONE improve the efficiency of our business. One such example is the improvement in our ability to service our customers with replacement parts. EXECUTONE keeps a computerized record of our vehicles' replacement parts inventory. By using the Teletrac System, we can locate vehicles that carry a needed part and establish which one is nearest to a customer. This allows us to provide timely response to a customer having problems with their phone system.

In addition, fuel efficiency of our fleet has increased by reducing the amount of miles the vehicles travel: our backlog is reduced by being able to dispatch service vehicles more efficiently. The Teletrac system allowed us to be a more conscious corporate system by reducing drive time and fuel usage of our fleet vehicles and increasing customer service.

Sincerely,

Gerald N. Quindt
Operations Manager

JQ:kaw

SSS SUPERIOR SIGNAL SERVICE

November 25, 1991

Mr. Ned Carey
Account Executive
International Teletrac Systems Inc.
9800 La Cieniga Blvd., Suite 800
Inglewood, Ca 90301

Dear Mr. Carey,

It is indeed a pleasure to inform you of some recent developments as to the benefits we have realized from the use of the Teletrac System. I contacted our insurance company and inquired about possible savings we might be entitled to as a result of the tracking capability of Teletrac.

In September the Teletrac system was demonstrated to our insurance broker. The benefits were described in full as to how Teletrac has enhanced our ability to not only track our vehicles but to document the information as well. We indemnify all of our clients with respect to our operations and compliance to our contracts. Our broker was particularly interested in the ability to prove that our people were where they are supposed to be when they are supposed to be there. Due to the emergency public service nature of our business, this is our most serious exposure.

On November 1st, our broker quoted the new rates for our insurance. Due almost exclusively to Teletrac and our ability to document the activities of our vehicles, we realized a savings on not only the automotive portion of the insurance but a significant consideration was given to the liability section as well. In an environment where costs are constantly rising, we have realized savings of over $ 6,000 per year on our general insurance premiums.

I am sure that as time goes on, we will continue to experience benefits from the Teletrac system, so I thank you in advance for those benefits.

Respectfully,

H. Chet Galland
President & General Manager

HCG/pl

Los Angeles County Office of Education

Stuart E. Gothold
Superintendent

Los Angeles County
Board of Education

Frank J. Alderete
President

Barbara G. Pieper
Vice President

Lewis P. Bohler, Jr.

Jeanne Breunig

Manuel Gallegos

Max E. Ragland

Michaelene D. Wagner

November 22, 1991

Mark Rich
Senior Account Executive
International Teletrac Systems
9800 La Cienega Boulevard, Suite 800
Inglewood, CA 90301

Dear Mr. Rich:

Following our recent telephone conversation I reflected upon the remarkable working relationship the Los Angeles County Schools has enjoyed with Teletrac for more than two years. I was convinced early on in our review of Teletrac that an accurate and cost effective vehicle location system could play an important role in the school bus industry. Today, Teletrac continuously exceeds my expectations for a vehicle location system.

Transportation services the county office provides to school districts throughout the 4,000 square mile area of Los Angeles county has improved significantly since we've installed the Teletrac system. This is due in large part to the fact that we know the exact location of contract school buses at all times.

Our emergency planning for earthquakes and other disasters has been aided by utilizing the Teletrac system, giving us the exact location of our buses in the event of an emergency.

Additionally, transporting handicapped children is a large part of our service. We are able to predict accurate estimated times of arrival for pick-up so parents do not need to leave their children waiting for buses. We are also able to report to parents the time of drop off.

Finally, the Teletrac system has assisted us in dealing with a critical problem that plagues our industry, school bus driver turnover. In the first weeks of employment, new drivers routinely get lost. By using the Teletrac system in conjunction with our two way radios, we are able to give new drivers directions on how to get to a school or pick-up point.

Sincerely,

Charles Devlin
Transportation Officer

CD:hs

D

DIVERSIFIED PARATRANSIT, INC.

1400 EAST MISSION BOULEVARD

POMONA, CALIFORNIA 91766

(714) 622-1316 • (714) 986-1136

November 25, 1991

Mr. Mark Rich,

Sr. Account Executive

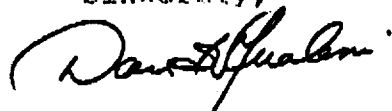International Teletrac Systems, Inc.

Inglewood, Ca. 90301

Dear Mr. Rich:

Diversified Paratransit operates bus services in the Los Angeles area with the purpose of giving rides to elderly and handicapped individuals. Our service includes bus transportation for Regional Centers, nursing homes and Dial-A-Ride for the elderly individuals.

We utilize the Teletrac system for the purpose of providing better service to our clients. With this system we can locate the closest vehicle to a pick up point, saving waiting time for our clients. Also by knowing the location of our vehicles we can accurately quote estimated times of arrival for programs or relatives.

We just wanted to let you know how valuable your system has been in improving the lives and well-being of our elderly and handicaped customers.

Sincerely,

Director of Maintenance

E

April 2, 1992

Dear Mr. Rich:

I would like to thank you for your persistence in selling
the Teletrac system to me. When you first gave me a
demonstration I was skeptical of the application for my
company. However, I have since discovered that the Teletrac
system is indispensable to my business.

In the last six months, we have had three of our vehicles
stolen. By using the Teletrac system, the three vehicles
were all recovered in a short amount of time. In two of
these instances, suspects were apprehended for the theft.

If I can be of service to you or Teletrac, please do not
hesitate to call me.

Sincerely,

Rick Hernandez
President